A PRELIMINARY REPORT ON NUMERICAL SEA CONDITION FORECASTS

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[Manuscript received April 19, 1957; revised June 18, 1957]

ABSTRACT

Since July 1956 the Joint Numerical Weather Prediction Unit at Suitland, Md., has been making machine forecasts of sea conditions on an operational basis. These prognoses are based on the 1,000-mb. wind forecasts derived from the two-level, thermotropic model currently in use at JNWP. Two different sea-forecast models have been tested to date. The first utilized only the forecast winds at the end of the forecast period and therefore yielded "fully developed waves." A model incorporating "duration" in a crude manner is now in daily operation. This paper describes both methods, compares the numerical results with observed conditions, and outlines future plans.

1. INTRODUCTION

In describing and forecasting sea conditions, one generally deals with two more or less distinct problems—wind-driven waves, often called "sea," and another class of waves called "swell." Swell is defined as waves which have moved outside of the locale in which they were generated, whereas wind waves are those presently in a specific generating area.

In the first machine forecasts of sea conditions attempted at the Joint Numerical Weather Prediction Unit (JNWP), only wind waves have been considered. The reasons for neglecting swell are primarily two; first, the total problem is thereby greatly simplified, and second, in most cases swell is a less important factor in the preparation of prognostic sea-condition charts. This does not mean that swell is always negligible. As a matter of fact, in some areas (e. g., subtropical high pressure cells) swell is frequently the only contributing factor, and more advanced forecast models will undoubtedly have to incorporate this feature.

Considering wind-driven waves alone, then, the principal parameters which define the height to which they will finally grow are windspeed, duration, and fetch. Obviously, a 50-knot wind blowing for only 10 minutes will not generate waves as high as the same wind blowing for a period of 10 hours. Similarly, a 50-knot wind flowing across a puddle 100 yards in diameter will not generate waves as high as it would on a lake 100 miles in diameter.

The "sea" at any particular location is actually composed of waves covering a wide band of heights and wavelengths. It has become more or less standard practice among oceanographers and forecasters to deal with a certain segment of the entire wave spectrum when attempting to describe and/or forecast the state of the sea. The segment which is customarily chosen includes the top third of the height spectrum, and the average or "significant" height of these waves is what one usually reports and attempts to forecast. In this paper, it is to be understood that this convention has been followed and all references to "wave height" really mean "significant wave height."

One of the products of JNWP which is available on a daily basis is a numerical forecast of the 1,000-mb. pressure heights at points on a 30×34 grid covering approximately two-thirds of the Northern Hemisphere. The grid interval is 381 km. at 60° N. From these forecast heights one can readily obtain the surface winds which serve as the basis for the sea-condition prognostication. A two-level model of the atmosphere developed by Thompson [1] is currently being used at JNWP to make the 1,000-mb. forecast.

Since the basic forecasts are an operational requirement placed on JNWP and are therefore run on a daily schedule, it was felt that sea-condition forecasts might turn out to be a relatively inexpensive byproduct. For this reason it was decided to undertake an investigation of numerical sea forecasting models wherein relevant parameters would be treated in decreasing order of importance. The machine forecasts described in this preliminary report represent the first phase of this investigation and are essentially an attempt to apply numerical methods to the subjective, prognostic technique developed in the Division of Oceanography, U. S. Navy Hydrographic Office.

2. FULLY DEVELOPED WAVES

Probably the simplest model which one can use for the numerical prediction of sea conditions assumes that both duration and fetch are infinite. Under these conditions the sea is said to be fully arisen. The height to which a wave will grow is assumed to be dependent only upon the

*Any opinions expressed by the writer are his own and do not necessarily reflect the views of the Navy Department at large.

windspeed and the maximum allowable height for any speed is often called the "fully developed wave height."

A number of empirical and semi-empirical relationships between significant wave height and windspeed have been found in the case of fully arisen seas (e. g., Cornish [2], Rossby and Montgomery [3], Pierson, Neumann, and James [4]). These authors have found that the heights vary with different powers of the windspeed ranging from the first to the fifth. Since the numerical forecast yields 1,000-mb. pressure heights at grid points, the wind is customarily computed over an interval of two mesh lengths. In order to obviate the use of a square-root routine (the total wind must be determined from two components) the equation of Rossby and Montgomery was selected for computing the fully developed sea-heights, namely:

$$H=\frac{A}{g}V^2 \tag{1}$$

where H is the fully developed wave height, A is a non-dimensional constant taken to be 0.3, g is gravitational acceleration, and V is windspeed. In the application of equation (1), 70 percent of the geostrophic wind at 1,000 mb. was used for V. (This was done to take into account the various elements that produce subgeostrophic winds at the sea surface.)

Using the 36-hour prognoses derived from the thermotropic model, numerical forecasts of fully developed wave heights were made at JNWP for several months. As one might expect, the results were far from good when compared with actual conditions. On the other hand, they were not completely discouraging either; in areas where the assumptions of unlimited fetch and duration were reasonably true, the predicted and observed wave heights agreed remarkably well, indicating that equation (1) is basically correct. The tendency was to predict high waves to be too high and low waves too low. These discrepancies are primarily due, it appears, to the assumption of infinite fetch and duration in the case of high waves, and to the neglect of swell in areas of weak winds where the waves were predicted to be too low.

Analyses prepared at the U. S. Fleet Weather Central (FWC), Washington, D. C., following the methods developed at the U. S. Navy Hydrographic Office (Schule and Ropek [5]) have been used to test the accuracy of the numerical computations. The FWC analyses are based primarily on ship observations; however, in areas of sparse data, continuity, and computations utilizing the prediction curves of Bretschneider [6] and others are used to fill in. In figure 1a is shown a chart of wave heights determined from equation (1) using the observed 1,000-mb. height field at 1500 GMT January 8, 1957, as input data. By comparing with the sea-condition analysis at 1230 GMT for the same day, figure 1c, one can readily see that in general the patterns are quite similar; however, the waves obtained from the numerical computation are much too high in the areas of strong winds.

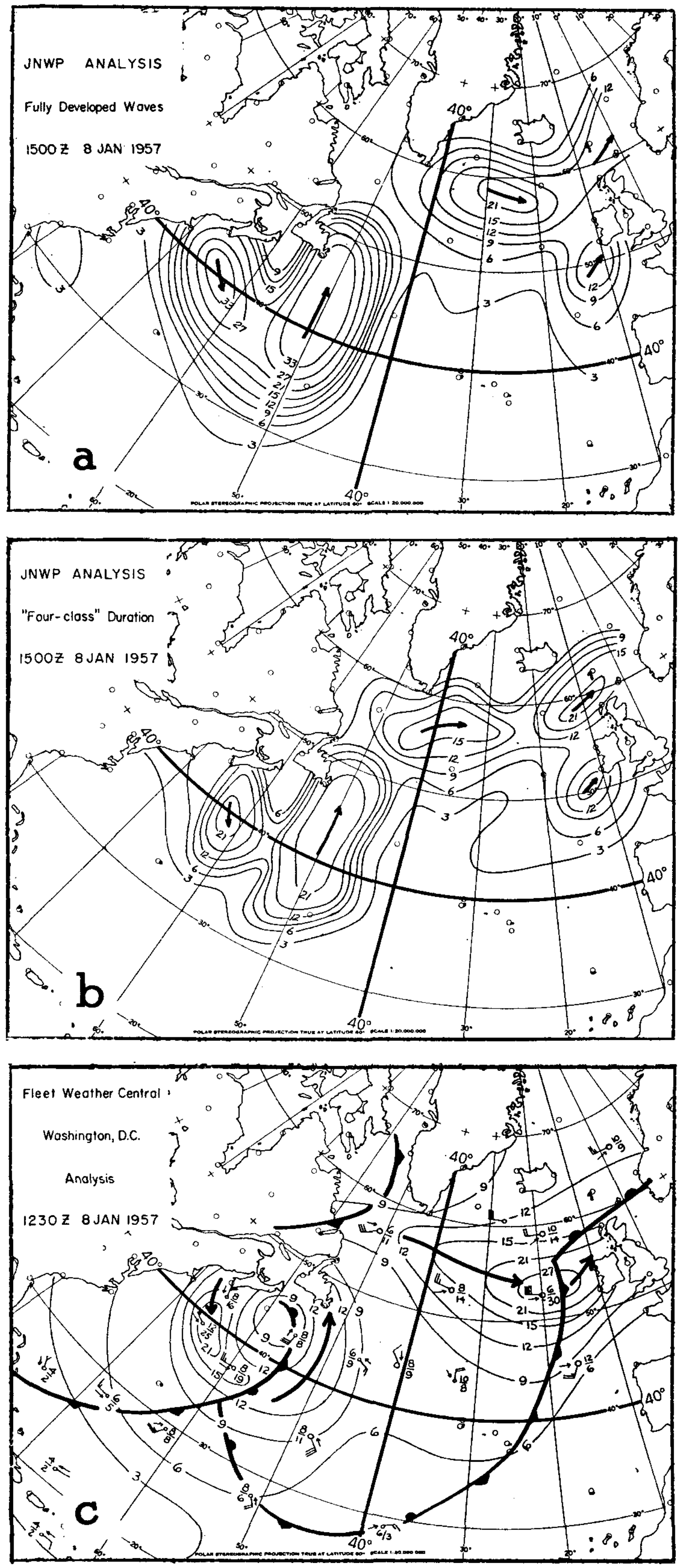

Figure 1.—Wave-height comparisons for January 8, 1957: (a) JNWP analysis of fully developed waves at 1500 GMT; (b) JNWP analysis at 1500 GMT using the four-class, duration model; and (c) Fleet Weather Central analysis for 1230 GMT. Wave heights in feet.

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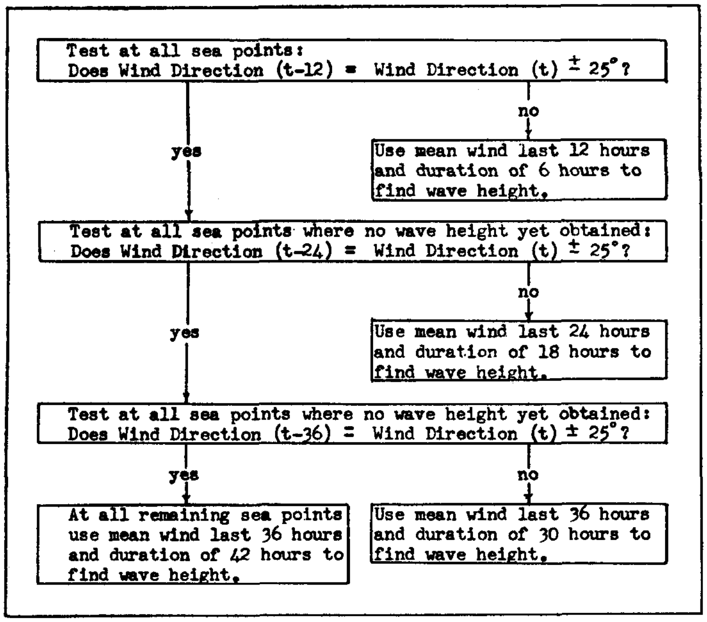

FIGURE 2.—Flow diagram for four-class, duration model outlining the method of computation.

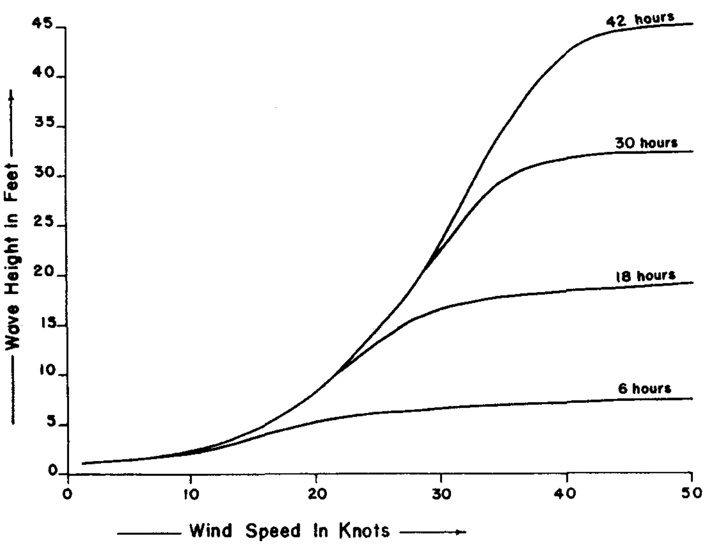

FIGURE 3.—Graph of wave-height versus wind speed curves used in the four-class, duration test. Duration in hours. (After Pierson, Neumann, and James [4].)

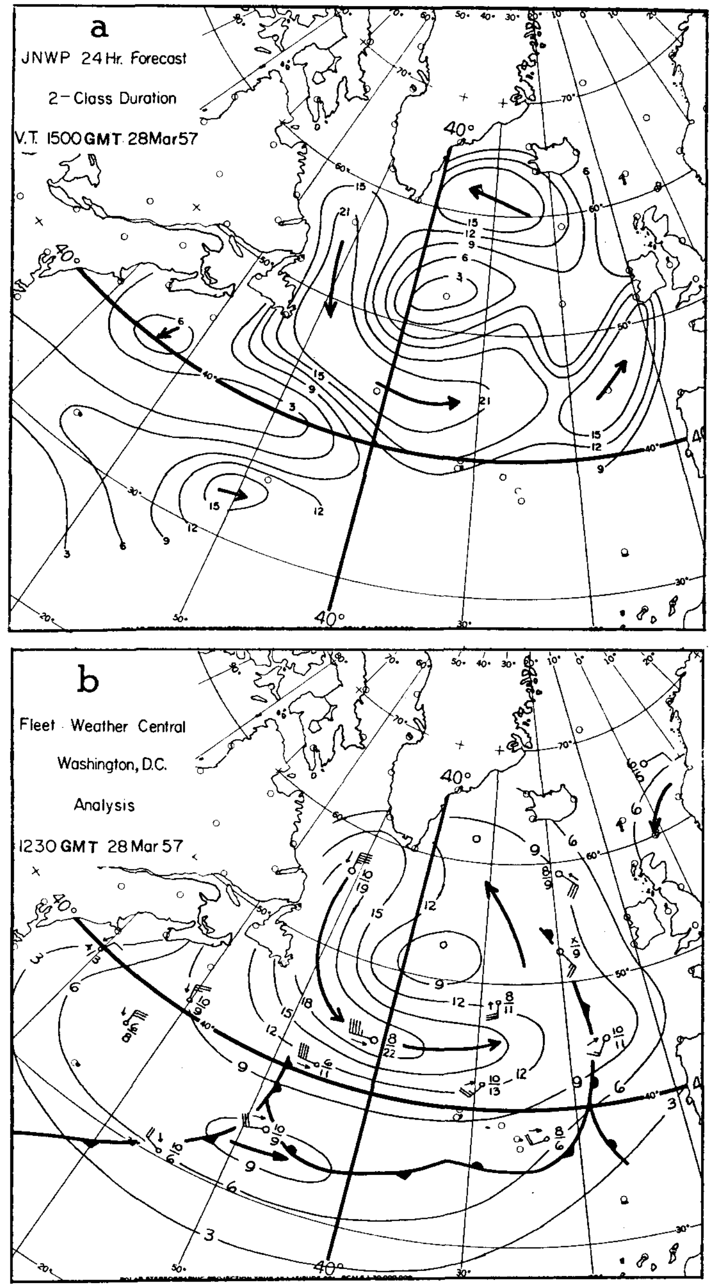

FIGURE 4.—(a) Example of a numerical, 24-hour wave forecast (two-class, duration) verifying at 1500 GMT March 28, 1957, and (b) Fleet Weather Central analysis of observed heights at 1230 GMT the same day.

3. EFFECT OF DURATION

The curves of Sverdrup and Munk [7] and Neumann [8] indicate that the effect of duration is usually more important than that of fetch except in particular situations (e. g., strong offshore winds). In order to determine just how much the incorporation of duration would modify the fully developed wave patterns shown in figure 1a, a duration model was tested on the same case. Four observed 1,000-mb. fields at 12-hour intervals prior to and including 1500 GMT January 8, 1957, were used as input data. In other words, it was assumed a priori that a perfect wind forecast was available in order to eliminate this source of error from the comparison.

The computational procedure for the "four-class" duration model is shown in the form of a flow diagram in figure 2. Time (t) represents the end of the forecast period; ($t-12$) is 12 hours earlier, etc. The wave height versus windspeed relationships for the four allowable duration times of 6, 18, 30, and 42 hours (from Pierson, Neumann, and James [4]) were stored in the computer. Figure 3 shows these same data plotted as four duration curves on a chart having windspeed as the abscissa and wave height as the ordinate.

The results of the four-class duration computation are shown in figure 1b. All-in-all, the wave heights agree more closely with those observed than in the case of fully developed waves. In particular, the maxima are lower than those obtained from equation (1). The 21-foot maximum to the rear of the cold front off Boston is almost exactly reproduced by the numerical method. The maximum ahead of the occluded front is still computed to be too high; there is some doubt, however, about the analysis here, for no ship reports were received from the area of strongest southerly winds. The maximum west of Ireland split into two centers in the duration test; nevertheless, the overall correspondence is good. The improvement in the Pacific area (not shown here) was even greater, especially around a severe storm in midocean.

Throughout March 1957, 24-hour forecasts of wave heights based on an extremely simple, two-class duration model were made on an operational schedule. In this series of tests the 12- and 24-hour, 1,000-mb. forecasts were used to determine the wind speed and direction. If the wind shifted more than 25° in direction during the 12-hour interval, a duration of 6 hours was assumed to apply; otherwise, the duration was arbitrarily taken to be 24 hours. Figure 4 shows an example of a numerical forecast and the verifying analysis. A summary of the results obtained during March 1957 at three locations in the North Atlantic is shown in figure 5. The forecast and observed wave heights transmitted via facsimile from the U. S. Fleet Weather Central are presented for comparison.

Monthly mean values of forecast minus observed heights ($F-O$) divided by observed heights (O) have been determined for the three points. At latitude 55° N., longitude 15° W., the objective forecasts had a mean error of 43 percent compared with 19 percent for the subjective forecasts made at the Fleet Weather Central. This point is closest to the edge of the numerical forecast grid, and the predicted 1,000-mb. heights are apt to be in error here due to boundary influences. This might help to explain this difference; however, whatever the cause, the "hand" forecasts were clearly superior at this point. At the other two locations the numerical method (in spite of the crudeness of the model) was close to being competitive. Errors of 28 and 36 percent obtained for the JNWP forecasts compared with 25 and 29 percent for those from the weather central. It should be pointed out that there is a 2½-hour time difference between the end of the numerical forecast period and the observation time used in making the comparisons. Wave patterns can change appreciably in this time, and it may well be that the numerical method is truly competitive here.

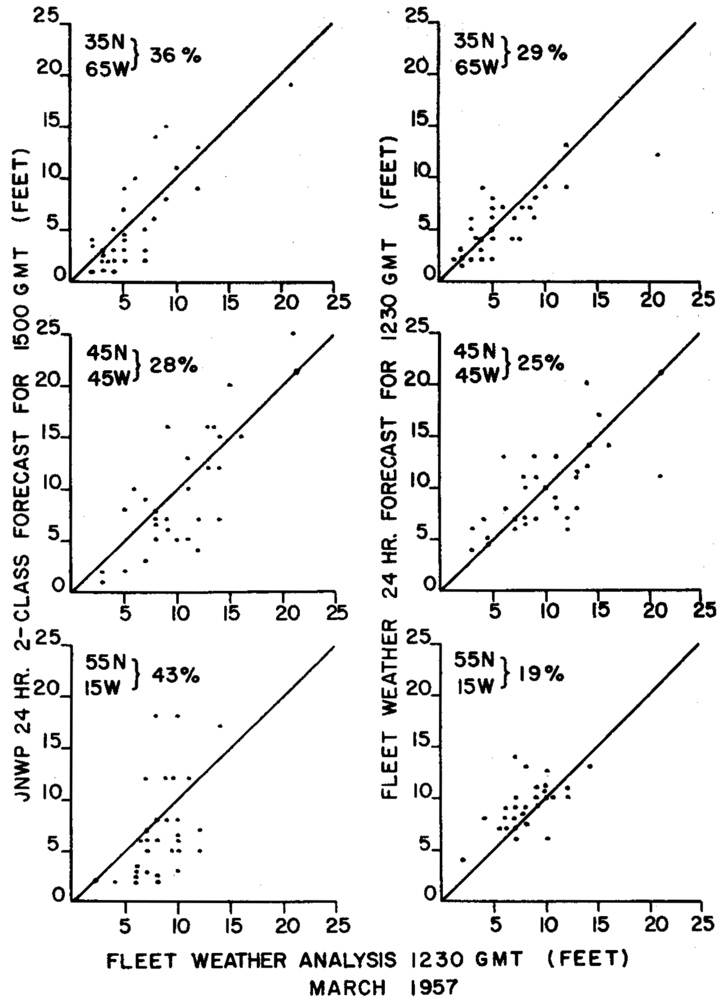

Figure 5.—Scatter diagram of predicted versus observed wave heights for JNWP and FWC forecasts (24 hour) at three Atlantic points during March 1957. Location of point and mean of forecast minus observed over observed heights, $(F-O)/O$, (percent) given in upper left of each diagram.

4. CONCLUSIONS

From the 9 months of cases which have been run at JNWP, the following somewhat preliminary conclusions are offered:

1. Computations of fully developed seas yield fair results in general, but tend to overforecast high waves and underforecast weak ones. The results at 24 and 36 hours are not competitive with subjective techniques.

2. Incorporation of "duration" into the numerical forecasts led to an appreciable improvement in quality. Over the Atlantic during March 1957, the results at 24 hours were almost as good as those obtained by experienced subjective forecasters. The extremely simple, two-class, duration model used during March 1957 appears to be capable of forecasting the gross pattern rather well; however, it is also clear that a closer determination of the duration time is desirable.

3. Any numerical forecast of sea conditions will be only as good as the numerical forecast of surface winds upon which it is based. To date, the machine forecasts of low-level flow patterns have not been as good as those prepared by the experienced synoptic meteorologist (even though the reverse may be true already at upper levels).

This need not discourage further research, however, for improvement in low-level numerical prediction can be expected to continue.

4. Assuming that fetch is infinite does not appear to be too restrictive in most cases. It would probably suffice to correct this approximation in regions of strong, offshore flow.

5. Neglecting swell can lead to significant errors in limited areas under special conditions. Any refined forecast technique should attempt to include the movement of at least the largest waves outside the generating area and treat their decay for a limited period of time.

5. FUTURE PLANS

The IBM model 701 electronic computer which was used in all of these tests is being replaced at JNWP by the IBM 704. On the 701, a numerical forecast of wave heights for two-thirds of the Northern Hemisphere's ocean area required only 5 minutes of machine time (once the 1,000-mb. fields were available). When low-level wind forecasts are forthcoming from the IBM 704, it should be possible to cover the entire Northern Hemisphere in 5 minutes and at the same time use a more refined sea-forecast model. With these considerations in mind, the present plan is first to program a model which will determine duration to the nearest hour and correct for fetch in the vicinity of the coasts. Because of the change-over to a new machine, wave forecasting on an operational basis will be discontinued at JNWP until a two-level atmospheric model is running on the IBM 704.

ACKNOWLEDGMENTS

The author would like to express his appreciation to Capt. W. E. Oberholtzer, Jr., USN, for his continuous encouragement during the progress of this study. The subjective forecasts used in the comparisons were prepared by the duty aerologists at the U. S. Fleet Weather Central, Washington, D. C. A number of very fruitful discussions were held with staff members of the Division of Oceanography, U. S. Navy Hydrographic Office, during the past year, and their suggestions for future lines of attack are most welcome.

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